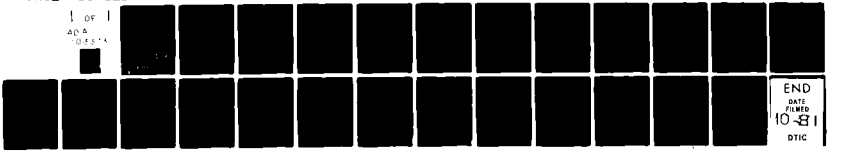
AD-A103 373 WASHINGTON STATE UNIV PULLMAN DEPT OF PHYSICS F/G 20/11
FRACTO-EMISSION FROM POLYMERS.(U)
AUG 81 J T DICKINSON N00014-80-C-0213
UNCLASSIFIED NL



AD A103373

LEVEL II

12

DTIC
ELECTE
AUG 27 1981
S D
A

This document has been approved for public release and sale; its distribution is unlimited.

DTIC FILE COPY

DEPARTMENT OF PHYSICS

81 8 27 019

OFFICE OF NAVAL RESEARCH
Contract N00014-80-C-0213
Project NR 092-558

Annual Technical Report
August 1981

FRACTO-EMISSION FROM POLYMERS

J. Thomas Dickinson

Department of Physics
Washington State University
Pullman, Washington 99164

DTIC
ELECTE
AUG 27 1981
A

Reproduction in whole or in part is permitted for any purpose of the United States Government.

Approved for Public Release; Distribution Unlimited.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Annual Technical Report	2. GOVT ACCESSION NO. AD-A103373	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Emission of Electrons and Positive Ions from Fracture of Materials		5. TYPE OF REPORT & PERIOD COVERED Annual Technical Report June 1980 - June 1981 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. T. Dickinson		8. CONTRACT OR GRANT NUMBER(s) N00014-80-C-0213
9. PERFORMING ORGANIZATION NAME AND ADDRESS Physics Department Washington State University Pullman, WA 99164		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 092-558
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Power Program Arlington, VA 22217		12. REPORT DATE August 1, 1981 13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

fracture, delimination, crack propagation, fracture surfaces, interfacial failure, exo-emission, electron emission, tribo-stimulated exo-emission, chemi-emission, surface charging, fracture of: crystalline materials, insulators, polymers, fibers, filaments, glass, mica, carbon, rubber, fiber-reinforced epoxy, glass-filled polybutadiene.

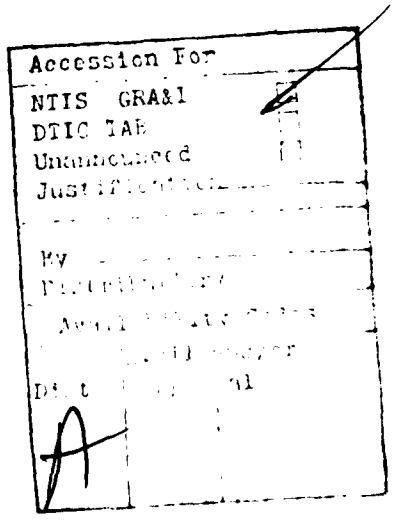
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Progress in the investigation of fracto-emission (FE) from polymers, composites, and other materials is summarized in this report. The unique emission from interfacial failure is described for fiber reinforced epoxy and polybutadiene filled with glass beads. Initial results of the determination of the mass of the positive ions, measurements of emission from Kevlar-epoxy, and a simple model for the observed decay from interfacial failure are discussed. Preliminary work including the role of cross-linking and the dependence of FE on crack velocity are mentioned.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

TABLE OF CONTENTS



I. Introduction

The major goals of the work this first year has been to examine the extent of fracto-emission phenomena accompanying and following the fracture of polymers, to measure the properties of this emission, and to determine the physical and chemical parameters which influence fracto-emission. A Technical Report describing some of this year's progress has recently been published, namely: Technical Report No. 1, "The Emission of Electrons and Positive Ions from Fracture of Materials," by J. T. Dickinson, E. E. Donaldson, and M. K. Park.[1] Only a summary of this work will be presented here. Recent extensions and new results will be noted also.

II. Results and Discussion

A. Survey of Fracto-Emitters

A wide range of materials were fractured in vacuum and the resulting charged particle emission detected. Detectors for both negative and positive charge emission were used. All materials were strained to failure, usually in tension. For brittle materials, three-point bending strain was used. Materials ranged from crystalline inorganic salts, ceramics, sugar, glassy polymers, elastomers, to composites. In all materials tested, emission was observed. The intensity and time dependence of the emission was material dependent.

For a few materials we used magnetic fields to probe the negative charge emitted for a negative ion component. No significant negative ion component was observed; i.e., the negative particles we observe appear to be predominantly electrons.

The intensity of the emission per unit cross-sectional area goes up as sample cross-section decreases. This may be due to either a higher probability of escape of the particle or the increase in elastic strain energy stored in the material (filaments have higher tensile strength).

B. Interfacial Failure in Composites

In systems where polymer/inorganic solid interfaces fail, we observe extremely intense and long lasting emission; millions of charged particles with emission that lasts for several tens of minutes. Much lower emission lasting only microseconds is observed when the separate constituents of the composites (e.g. glass, graphite, Kevlar, and epoxy) are fractured. Accompanying interfacial failure is considerably more charging of the surfaces

perhaps due to both emission and charge separation. In air, these surfaces are above the break-down potential of air, suggesting that the resulting surface charge density is not at all at its maximum. We have evidence that the density of surface charge is playing an important role in our observed FE. For example, the energy distributions of the electron and emission (EE) positive ion emission (PIE) are nearly identical and have a peak near 0 eV and a slowly decreasing tail that extends beyond 2 keV, the limit of our retarding potential energy analyzer. There have been reports of 40 keV electrons from interfacial failure between teflon and epoxy[2] and 120 keV electrons from cleavage of alkali halides.[3] Our interpretation of such measurements is that intense charging due to charge separation produces the electric fields that accelerate the emitted charges to these high energies.

In terms of phenomena accompanying crack growth in systems at high pressures, this charge separation could lead to considerable energy release in the form of breakdown and corona discharge as well as additional emission and surface bombardment by charged particles due to cascade effects.

C. Interfacial Failure in Filled Elastomers

When polybutadiane and solithane filled with glass beads is fractured we observe analogous effects like the composites: long, intense emission with a very similar decay curve lasting for several minutes. The emission intensity is sensitive to the volume percent of glass beads, increasing with bead concentration. Again, this enhanced emission is attributed to interfacial failure at the surface of the beads. The energy distributions of the EE and PIE show energies that fall from near zero eV to energies above 2 kV. Again, the role of intense charging could be significant at high pressures. The crack-tip would be filled with volatiles produced

by the fracture itself. Breakdown, corona discharge, and/or fracto-emission interacting with the gases and crack-walls could result in a number of chemical effects.

III. Most Recent Results

A. Mass of Positive Ions

Several attempts to measure the mass of the PIE emitted from polymer fracture were made using a quadrupole mass spectrometer. Because of the broad energy distribution extending to high energies, the quadrupole could not mass discriminate. Ions simply passed down the quadrupole section undeflected.

We have made progress in separating out the lower part of the energy distribution with a grid system and introducing bursts of these ions into a time-of-flight (TOF) mass spectrometer. With relatively low resolution we have examined the PIE from delamination of 3M Filament Tape; i.e. the separation between the polyester backing and the filaments which adhere by means of a natural rubber based adhesive. This mode of failure produces intense EE, PIE, as well as photon emission. The mass was determined by measuring the shift in the TOF spectrum as a function of voltage applied to the drift tube which was 25 cm in length. The crude value obtained was 120 ± 60 amu. Although the uncertainty is high, the measurement indicates that the PIE consists of relatively small fragments, possibly monomers or chain fragments produced by bond scission. We are attempting to improve our mass resolution and ion optics to better determine the PIE masses.

B. Kevlar and Kevlar-Epoxy Fracture

Similar to measurements performed on glass- and graphite-epoxy systems we also examined the EE and PIE from the fracture of 10μ Kevlar filaments DER 332, similar to the strands studied earlier. Figure 1 shows the PIE time distribution for the Kevlar filaments which decays exponentially with a time constant of 45 μs, similar to a number of polymers and certainly longer than

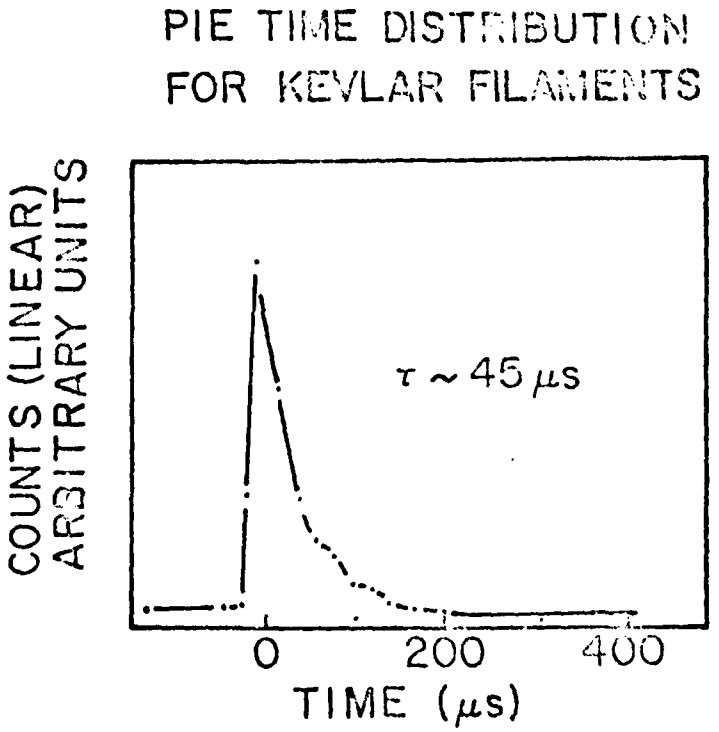


Figure 1. Time distribution for positive ion emission due to fracture of 10 micron Kevlar filaments. The time constant for the exponential decay is about 45 microseconds.

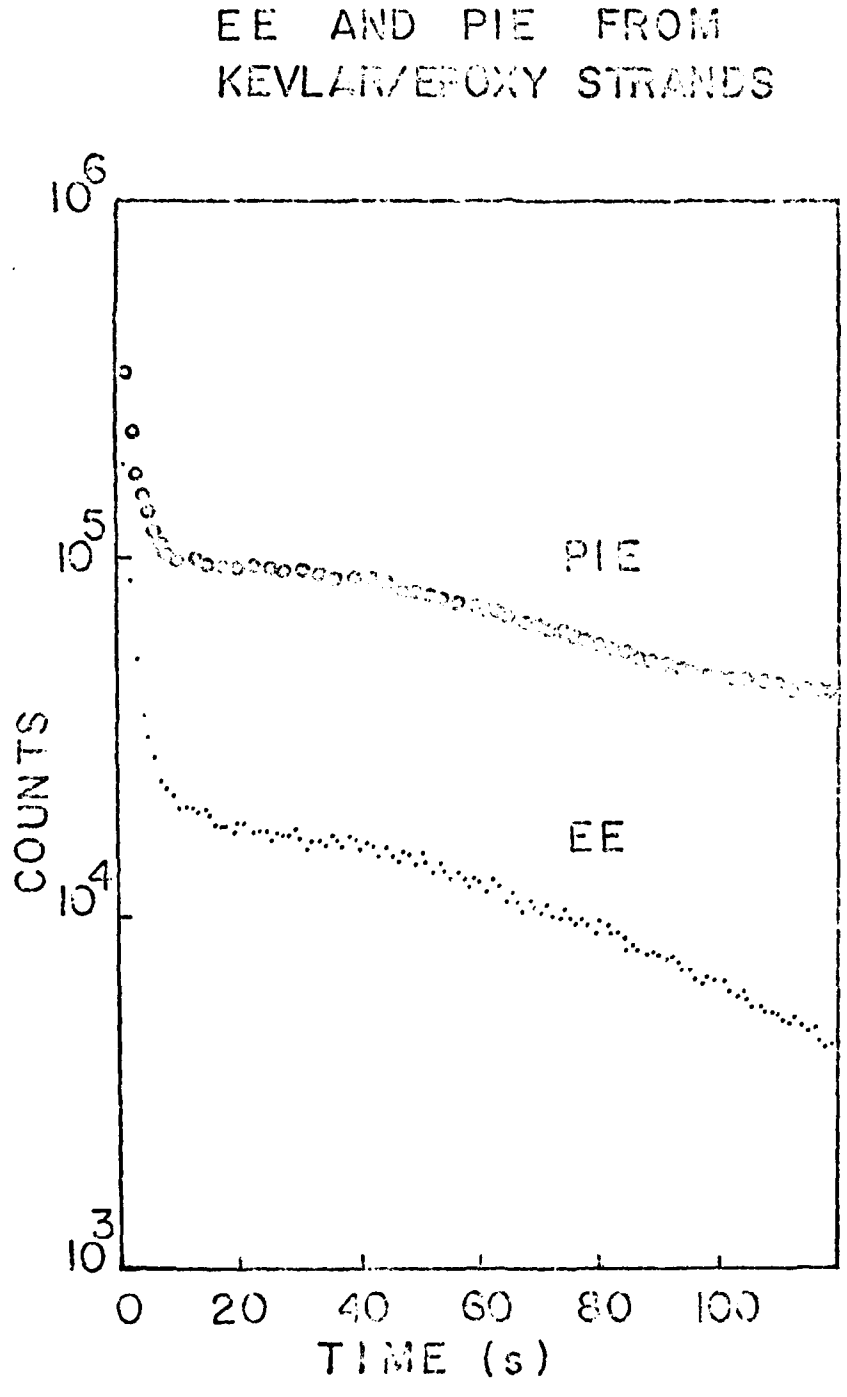


Figure 2. EE and PIE from the fracture of Kevlar/Epoxy strands on a log plot. The 10 micron kevlar filaments were in a DER 332 epoxy.

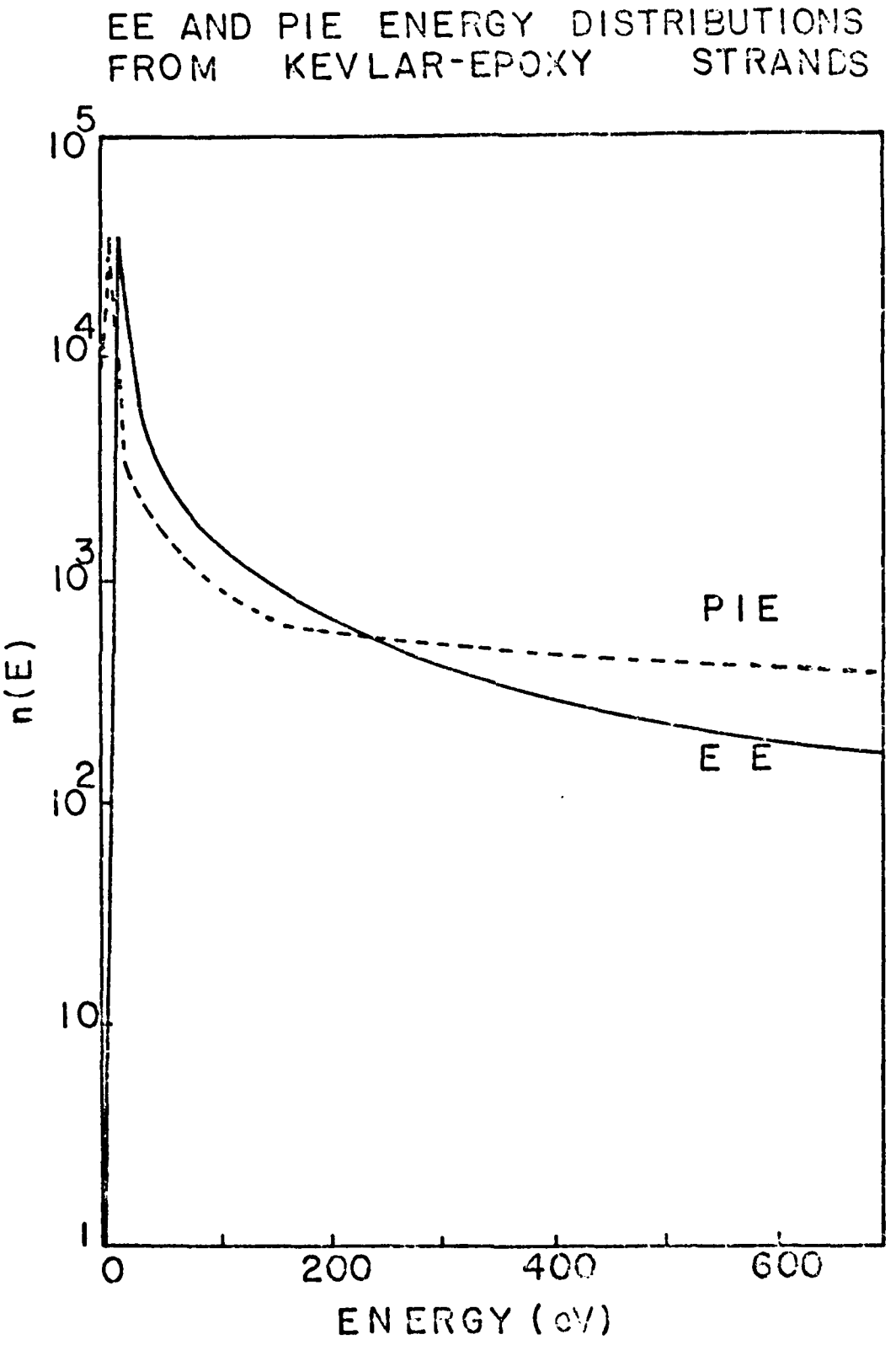


Figure 3. Energy Distributions for the EE and PIE due to fracture of Kevlar-Epoxy strands over the range 0-600 eV.

the inorganic filaments which had decay times of about 10 μs. The EE time distributions are quite similar.

If we then examine EE and PIE from Kevlar/Epoxy as seen in Fig. 2, we see that the emission is very long lasting. It has the characteristic initial decay from the peak, but has a departure in slope from simple exponential decay. This has been seen on a number of other systems involving adhesive failure (unpublished) and following the cleavage of mica. Nevertheless, the intense, long lasting emission again is attributed to the enhanced excitation that occurs from interfacial failure between the Kevlar filaments and epoxy. The intensity is higher than other filament-epoxy systems studied and so is the extent of interfacial failure. Fig. 3 shows the energy distributions on a log plot for both the EE and PIE.

C. Computer Fit of EE from E-Glass/Epoxy Strands

The decay from the composite systems has the appearance of either two exponential terms (suggesting two independent first order mechanisms at constant temperature, or a modified first order process that decays to a simple first order curve. Figure 4, curve A is a nonlinear least-squares fit of a typical EE decay curve for E-glass/epoxy using two exponential terms. The best fit was obtained with time constants 0.83 s and 21 s. C_1 and C_2 were also adjustable parameters. Although the fit looks fairly good, one sees that there are deviations.

An improved fit of the data was obtained by assuming a simple first-order process given by:

$$\frac{dN}{dt} = \nu\, N \exp(-E_A/kT)$$

where N = the number of excitations whose decay produces electrons, ν = a pre-exponential factor, E_A = activation energy for thermal stimulation of the excitation decay. We also assume a rise in temperature at the surface where the sites

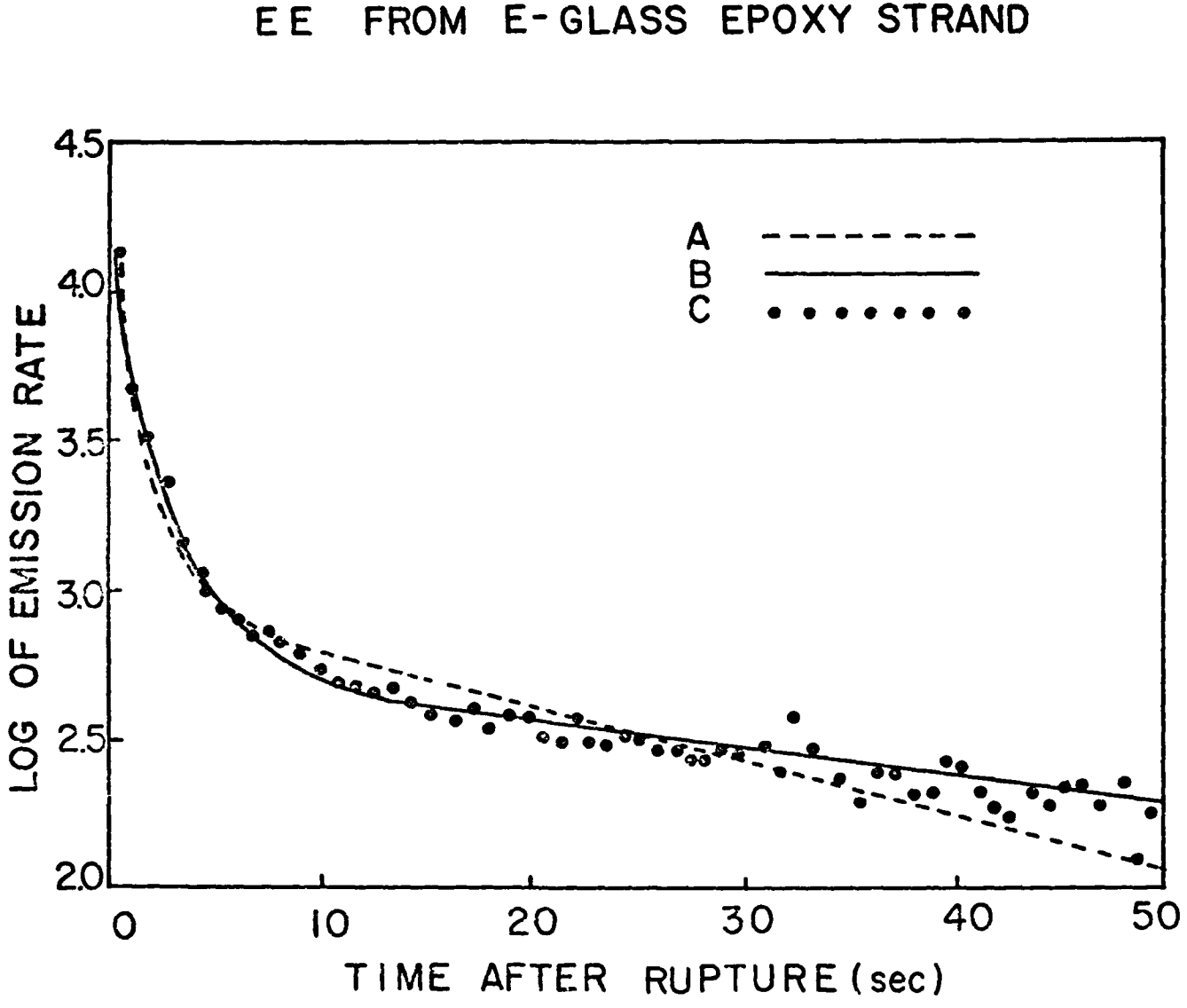


Figure 4. Log plot of the first 50 seconds of the EE from E-Glass/Epoxy. The dots are the data points. Curve A (dashed line) represents a non-linear least squares fit to the equation $C_1\exp(-t/\tau_1) + C_2\exp(-t/\tau_2)$; where τ_1 = 0.83 s and τ_2 = 21 s. Curve B (solid line) represents the least squares fit to the first order differential equation with a rise in temperature that falls exponentially.

exist. This temperature is expected to fall exponentially as follows:

$$T(t) = T_{room} + \Delta T(\exp - t/\tau) \ .$$

Figure 4, curve B shows the fit obtained with the parameters ΔT = 400C, E_A = 0.1 eV, and τ = 2.6 s.

This model is being applied to other data sets for filled polymers and other epoxy-filament systems If valid, it suggests a way to determine the surface temperature immediately after fracture. It would also predict that at elevated temperatures the rate of decay of the after-emission would be higher, which we plan to check experimentally.

D. Other Current Work

Other work which is too preliminary to report here will just be mentioned for completion.

1) We have measured the EE and PIE from un-notched polybutadiene filled with glass beads under tensile strain before rupture. We see a clear peak in emission that appears when the material "whitened" presumably due to detachment of the beads from the polymer matrix. The particle emission we observe is most likely due to this interfacial failure where the vacuola created opens a portion to the vacuum. The latter is necessary for the released particles to reach the detector. Measurements are being made of the strain at onset of this emission to indicate when bead detachment is initiated. Also, the shape of the emission vs. strain curve may be related to the distribution of detachment vs. strain.

2) We have measured the total emission and decay curves of unfilled elastomers, namely SBR (butadiene-styrene co-polymer) and polybutadiene before and after exposure to UV-radiation or γ-rays (3000 Curie Co-60 source). Both types of radiation produced enhanced emission both

during and following crack propagation. Swelling measurements show that the degree of cross-linking increased. It is felt that because of enhanced cross-linking, fracture produces more molecular fragments and free-radicals that can enter into the emission process. This work is being quantified.

3) Crack-tip motion in elastomers at room temperature is sufficiently slow that elementary methods can be used to measure displacement vs. time while simultaneously measuring EE or PIE. We are using a standard video camera and recorder. Our recent measurements show a strong dependence of FE intensity on crack velocity. In some materials we have found that on millisecond time scales, our detectors are completely saturated (implying detector count rates $\geq 10^6$ per second) at crack velocities $\cong 10^2$ cm/sec. In order to see the shape of the emission curves vs. time at high velocities we plan to replace the detector with a standard electron multiplier which has a lower sensitivity and a larger dynamic range. At some point we will want to increase our strain rate and crack-motion measurements.

IV. Conclusion

The underlying significance of our results to date on FE from polymers is that when a crack propagates through the material the fracture surfaces are in a highly excited, nonequilibrium state. This involves broken bonds, liberated fragments (e.g. free radicals, atoms, charged species), defects, intense charge separation (particularly in the case of interfacial failure), and a localized rise in temperature. The observed FE is a measure of the degree of this excitation and is evidence of considerable chemical activity. The fracture event produces activated species, such as free radicals, that undergo recombination reactions releasing sufficient energy to produce particle and photon emission. The charging of surfaces certainly is responsible for the high energy particles observed and may also effect the emission intensity. This could be due to an influence on the mobility of active species near and on the fracture surface as well as a direct coupling of the E-field to electronic transition probabilities in excited species. The fact that we see such enhanced effects when interfaces are involved is likely due to a) the different types of chemical species produced by adhesive failure (as compared to cohesive failure) and b) the larger degree of charging that seems to occur with interfacial failure.

In this report we have outlined the progress of our first year's efforts to study the Fracto-Emission from polymers. We have presented evidence of such emission for a wide range of materials and shown that interfacial failure produces intense, long-lasting emission. We are finding that the emission is probably involving the production and decay of free radicals and that surface charging is playing an important role, perhaps in the filling of newly created surface states and influencing the mobility of active

species. The potential of using FE for detecting filler detachment, measuring crack-tip motion at very high crack velocities, and relating crack motion to polymer morphology appears very high. Also, FE can serve as a probe on the microsecond time scale of the activity of the freshly created crack walls. All these studies have direct applicability to fracture phenomena in energetic materials.

V. Acknowledgments

We wish to thank R. L. Moore, Lawrence Livermore Laboratory, for providing samples of filaments and fiber/epoxy strands, Dr. A. N. Gent, University of Akron Institute of Polymer Science, for supplying polybutadiene samples, and Dr. Y. Gupta. We also wish to thank Dr. L. L. Clements, NASA-Ames Research Center for useful discussions.

VI. Personnel Supported by this Project

J. T. Dickinson, Principal Investigator	25%
E. E. Donaldson, Professor of Physics	10%
M. K. Park, Graduate Student	50%
D. B. Snyder, Graduate Student	10%
B. J. Tillotson, Undergraduate Student	10%

VII. Fracto-Emission Talks and Papers Presented

"Electron and Acoustic Emission Accompanying Oxide Coating Fracture," International Conference on Metallurgical Coatings, San Diego (1980).

"Electron and Positive Ion Emission During Fracture of Oxide Coatings," AVS Conference, Detroit (November, 1980).

"Fractoemission," WSU, Department of Materials Science (December, 1980).

"Charged Particle Emission Accompanying Fracture," Materials Science Branch, NASA-Ames, December, 1980).

"Electron and Positive Ion Emission Accompanying Fracture," Navy Surface Weapons Center (October, 1980).

"Fractoemission from Polymers," Third ONR Meeting on Dynamic Fracture of Elastomers (February, 1981).

"Fractoemission from Solids," Lawrence Livermore Laboratories (March, 1981).

"Exoelectron Effects During Fracture," Conference on Stress Corrosion in Brittle Materials, NBS (June, 1981).

"Fractoemission from Composites," DOD-TTCP Critical Review: Characterization of Composite Materials, MIT (June, 1981).

VIII. References

1. J. T. Dickinson, E. E. Donaldson, and M. K. Park, J. Mat. Sci., to be published.

2. N. A. Krotova, N. N. Stefanovich, A. I. Vilensky, and Ju. A. Chrustalev, J. Adhesion 3, 325 (1972).

3. J. Wollbrandt, E. Linke, K. Meyer, Phys. Stat. Sol. (A) 27, K53 (1975).

DEF.

6/80

ENERGETIC MATERIALS RESEARCH

DISTRIBUTION LIST

	No. Copies
Assistant Secretary of the Navy (R, E, and S) Attn: Dr. R.E. Reichenbach Room 5E787 Pentagon Washington, DC 20350	1
Office of Naval Research Code 473 Arlington, VA 22217 Attn: Dr. R. Miller	10
Office of Naval Research Code 2008 Arlington, VA 22217 Attn: Dr. J. Enig	1
Office of Naval Research Code 260 Arlingon, VA 22217 Attn: Mr. D. Siegel	1
Office of Naval Research Western Office 1030 East Green Street Pasadena, CA 91106 Attn: Dr. T. Hall	1
Office of Naval Research Eastern Central Regional Office 495 Summer Street Boston, MA 02210 Attn: Dr. L. Peebles Dr. A. Wood	2
Office of Naval Research San Francisco Area Office One Hallidie Plaza Suite 601 San Francisco, CA 94102 Attn: Dr. P. A. Miller	1
Defense Technical Information Center DTIC-DDA-2 Cameron Station Alexandria, VA 22314	12
AFATL Eglin AFB, FL 32542 Attn: Dr. Otto K. Heiney	1
AFRPL Code PACC Edwards AFB, CA 93523 Attn: Mr. W. C. Andrepont	1
AFRPL Code CA Edwards AFB, CA 93523 Attn: Dr. R. R. Weiss	1
Code AFRPL MKPA Edwards AFB, CA 93523 Attn: Mr. R. Geisler	1
Code AFRPL MKPA Edwards AFB, CA 93523 Attn: Dr. F. Roberto	1
AFSC Andrews AFB, Code DLFP Washington, DC 20334 Attn: Mr. Richard Smith	1
Air Force Office of Scientific Research Directorate of Chemical & Atmospheric Sciences Bolling Air Force Base Washington, DC 20332	1
Air Force Office of Scientific Research Directorate of Aerospace Sciences Bolling Air Force Base Washington, DC 20332 Attn: Dr. L. H. Caveny	1
Anal-Syn Lab Inc. P.O. Box 547 Paoli, PA 19301 Attn: Dr. V. J. Keenan	1

DEF.

	No. Copies
Army Ballistic Research Labs Code DRDAR-BLP Aberdeen Proving Ground, MD 21005 Attn: Mr. L. A. Watermeier	1
Army Ballistic Research Labs ARRADCOM Code DRDAR-BLP Aberdeen Proving Ground, MD 21005 Attn: Dr. Ingo W. May	1
Army Ballistic Research Labs ARRADCOM Code DRDAR-BLT Aberdeen Proving Ground, MD 21005 Attn: Dr. Philip Howe	1
Army Missile Command Code DRSME-RK Redstone Arsenal, AL 35809 Attn: Dr. R. G. Rhoades Dr. W. W. Wharton	2
Atlantic Research Corp. 5390 Cherokee Avenue Alexandria, VA 22314 Attn: Dr. C. B. Henderson	1
Ballistic Missile Defense Advanced Technology Center P.O. Box 1500 Huntsville, AL 35807 Attn: Dr. David C. Sayles	1
Ballistic Research Laboratory USA ARRADCOM DRDAR-BLP Aberdeen Proving Ground, MD 21005 Attn: Dr. A. W. Barrows	1
Hercules Inc. Cumberland Aerospace Division Allegany Ballistics Lab P.O. Box 210 Cumberland, MD 21502 Attn: Dr. Rocco Musso	2
Hercules Inc. Eglin AFATL/DLDL Eglin AFB, FL 32542 Attn: Dr. Ronald L. Simmons	1
Hercules Inc. Magna Bacchus Works P.O. Box 98 Magna, UT 84044 Attn: Mr. E. H. DeButts	1
Hercules Inc. Magna Bacchus Works P.O. Box 98 Magna, UT 84044 Attn: Dr. James H. Thacher	1
HQ US Army Material Development Readiness Command Code DRCDE-DW 5011 Eisenhower Avenue Room 8N42 Alexandria, VA 22333 Attn: Mr. S. R. Matos	1
Johns Hopkins University APL Chemical Propulsion Information Agency Johns Hopkins Road Laurel, MD 20810 Attn: Mr Theodore M. Gilliland	1
Lawrence Livermore Laboratory University of California Livermore, CA 94550 Attn: Dr. M. Finger	1
Lawrence Livermore Laboratory University of California Livermore, CA 94550 Attn: Dr. R. McGuire	1
Lockheed Missiles and Space Co. P.O. Box 504 Sunnyvale, CA 94088 Attn: Dr. Jack Linsk Org. 83-10 Bldg. 154	1

DEF.

	No. Copies
Lockheed Missile & Space Co. 3251 Hanover Street Palo Alto, CA 94304 Attn: Dr. H. P. Marshall Dept. 52-35	1
Los Alamos Scientific Lab P.O. Box 1663 Los Alamos, NM 87545 Attn: Dr. R. Rogers, WX-2	1
Los Alamos Scientific Lab P.O. Box 1663 Los Alamos, NM 87545 Attn: Dr. B. Craig, M Division	1
Naval Air Systems Command Code 330 Washington, DC 20360 Attn: Mr. R. Heitkotter Mr. R. Brown	1
Naval Air Systems Command Code 310 Washington, DC 20360 Attn: Dr. H. Mueller Dr. H. Rosenwasser	1
Naval Explosive Ordnance Disposal Facility Indian Head, MD 20640 Attn: Lionel Dickinson Code D	1
Naval Ordnance Station Code 5034 Indian Head, MD 20640 Attn: Mr. S. Mitchell	1
Naval Ordnance Station Code PM4 Indian Head, MD 20640 Attn: Mr. C. L. Adams	1
Dean of Research Naval Postgraduate School Monterey, CA 93940 Attn: Dr. William Tolles	1
Naval Research Lab Code 6510 Washington, DC 20375 Attn: Dr. J. Schnur	1
Naval Research Lab Code 6100 Washington, DC 20375	1
Naval Sea Systems Command Washington, DC 20362 Attn: Mr. G. Edwards, Code 62R3 Mr. J. Murrin, Code 62R2 Mr. W. Blaine, Code 62R	1
Naval Sea Systems Command Washington, DC 20362 Attn: Mr. R. Beauregard SEA 64E	1
Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910 Attn: Dr. H. G. Adolph	1
Naval Surface Weapons Center Code R13 White Oak, Silver Spring, MD 20910 Attn: Dr. R. Bernecker	1
Naval Surface Weapons Center Code R10 White Oak, Silver Spring, MD 20910 Attn: Dr. S. J. Jacobs	1
Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910 Attn: Dr. M. J. Kamlet	1
Naval Surface Weapons Center Code R04 White Oak, Silver Spring, MD 20910 Attn: Dr. D. J. Pastine	1
Naval Surface Weapons Center Code R13 White Oak, Silver Spring, MD 20910 Attn: Dr. E. Zimet	1

DEF.

	No. Copies
Naval Surface Weapons Center Code R101 Indian Head, MD 20640 Attn: Mr. G. L. MacKenzie	1
Naval Surface Weapons Center Code R17 Indian Head, MD 20640 Attn: Dr. H. Haiss	1
Naval Surface Weapons Center Code R11 White Oak, Silver Spring, MD 20910 Attn: Dr. K. F. Mueller	1
Naval Surface Weapons Center Code R16 Indian Head, MD 20640 Attn: Dr. T. D. Austin	1
Naval Surface Weapons Center Code R122 White Oak, Silver Spring, MD 20910 Attn: Mr. L. Roslund	1
Naval Surface Weapons Center Code R121 White Oak, Silver Spring, MD 20910 Attn: Mr. M. Stosz	1
Naval Weapons Center Code 3853 China Lake, CA 93555 Attn: Dr. R. Atkins	1
Naval Weapons Center Code 3205 China Lake, CA 93555 Attn: Dr. L. Smith	1
Naval Weapons Center Code 3205 China Lake, CA 93555 Attn: Dr. C. Thelen	1
Naval Weapons Center Code 385 China Lake, CA 93555 Attn: Dr. A. Amster	1
Naval Weapons Center Code 388 China Lake, CA 93555 Attn: D. R. Derr	1
Naval Weapons Center Code 388 China Lake, CA 93555 Attn: Dr. R. Reed Jr.	1
Naval Weapons Center Code 385 China Lake, CA 93555 Attn: Dr. A. Nielsen	1
Naval Weapons Center Code 3858 China Lake, CA 93555 Attn: Mr. E. Martin	1
Naval Weapons Center China Lake, CA 93555 Attn: Mr. R. McCarten	1
Naval Weapons Support Center Code 5042 Crane, Indiana 47522 Attn: Dr. B. Douda	1
Rohm and Haas Company 723-A Arcadia Circle Hunsville, Alabama 35801 Attn: Dr. H. Shuey	1
Strategic Systems Project Office Dept. of the Navy Room 901 Washington, DC 20376 Attn: Dr. J. F. Kincaid	1
Strategic Systems Project Office Dept. of the Navy Room 1048 Washington, DC 20376 Attn: Mr. E. L. Throckmorton Mr. R. Kinert	2
Thiokol Chemical Corp. Brigham City Wasatch Division Brigham City, UT 84302 Attn: Dr. G. Thompson	1

DEF.

	No. Copies
USA ARRADCOM DRDAR-LCE Dover, NJ 07801 Attn: Dr. R. F. Walker	1
USA ARRADCOM DRDAR-LCE Dover, NJ 07801 Attn: Dr. N. Slagg	1
U.S. Army Research Office Chemistry Division P.O. Box 12211 Research Triangle Park, NC 27709	1
Institute of Polymer Science University of Akron Akron, OH 44325 Attn: Professor Alan N. Gent	1
SRI International 333 Ravenswood Avenue Menlo Park, CA 94025 Attn: Dr. Y.M. Gupta	1
Graduate Aeronautical Lab. California Institute of Technology Pasadena, CA 91125 Attn: Professor W.G. Knauss	1
Pennsylvania State University Dept. of Mechanical Engineering University Park, PA 16802 Attn: Professor Kenneth Kuo	1
Office of Naval Research 800 N. Quincy St. Arlington, VA 22217 Attn: Dr. G. Neece Code 472	1
Thiokol Corp. Huntsville Huntsville Div. Huntsville, AL 35807 Attn: Mr. J.D. Byrd	1
Washington State University Dept. of Physics Pullman, WA 99163 Attn: Prof. T. Dickinson	1
University of California Dept. of Chemistry 405 Hilgard Avenue Los Angeles, CA [illegible] Attn: Prof. M.F. [illegible]	1
Georgia Institute of Technology Office of Research Administration Atlanta, Georgia 30332 Attn: Professor Edward Price	1
Univ. of Utah Dept. of Mech. & Industrial Engineering MEB 3008 Salt Lake City, Utah 84112 Attn: Dr. Stephen Swanson	1
Space Sciences, Inc. 135 Maple Avenue Monrovia, CA 91016 Attn: Dr. M. Farber	1
Washington State University Dept. of Physics Pullman, WA 99163 Attn: Professor G.D. Duvall	1
Univ. of Maryland Department of Mechanical Eng. College Park, MD 20742 Attn: Professor R.W. Armstrong	1
The Catholic University of America Physics Department 520 Michigan Ave., N.E. Washington, D.C. 20017 Attn: Professor T. Litovitz	1
Sandia Laboratories Division 2513 P.O. Box 5800 Albuquerque, N.M. 87185 Attn: Dr. S. Sheffield	1
IBM Research Lab. K42.282 San Jose, CA 95193 Attn: Dr. Thor L. Smith	1
California Institute of Tech. Dept. of Chemical Engineering Pasadena, CA 91125 Attn: Professor N.W. Tschoegl	1
Northwestern University Dept. of Civil Engineering Evanston, IL 60201 Attn: Professor J.D. Achenbach	1
Office of Naval Research Structural Mechanics Program Arlington, VA [illegible] Attn: Dr. N.L. [illegible] Code [illegible]	1

DEF.

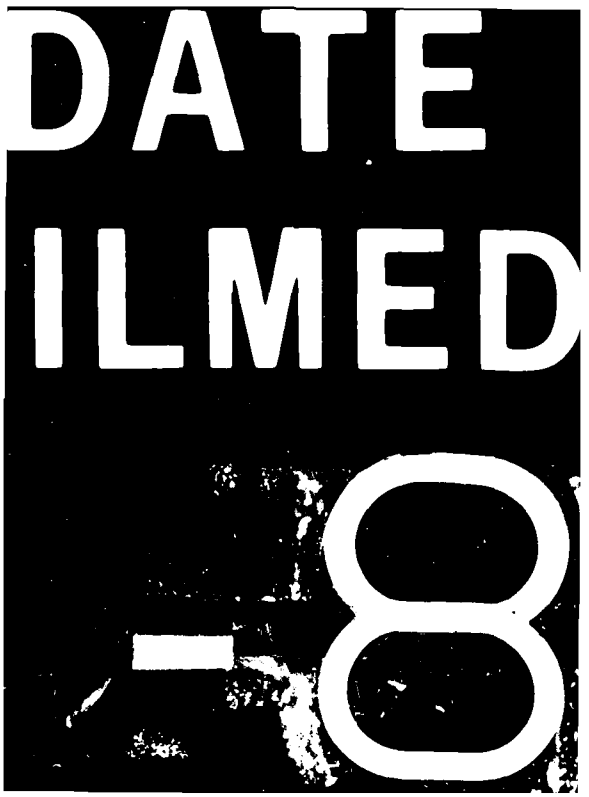
No. Copies

University of California 1
Berkeley, CA 94720
Attn: Prof. A.G. Evans

Texas A&M Univ. 1
Dept. of Civil Engineering
College Station, TX 77843
Attn: Professor Richard A. Schapery

SRI International 1
333 Ravenswood Ave.
Menlo Park, CA 94025
Attn: Mr. M. Hill

Los Alamos Scientific Laboratory 1
Los Alamos, NM 87545
Attn: Dr. J.M. Walsh


DATE
ILMED
-8